Using Measurements from the Disturbance Monitoring Package in SAGE III/ISS Data Processing

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SAGE III/ISS – Latest in the SAGE Series of Occultation Instruments

SAGE III/ISS Retrieves Profiles of:
- $O_3$, $NO_2$, Aerosols, $H_2O$ Vapor
- Other trace gases

Occultation Measurement Technique is performed by:
- Scanning Radiant Target (Sun/Moon) through the atmosphere
- Transmission is then converted to vertical profiles
- Requires precise pointing knowledge of the target
- Prior Missions operated in benign Mechanical Vibrational Environment

Tracking & Scanning Radiant Target accomplished by:
- Azimuth rotor assembly
- Elevation Scan Mirror
- [ISS] Disturbance Monitoring Package

[ISS] International Space Station experiences attitude fluctuations caused by:
- Maintaining TEA (torque equilibrium attitude)
- Reboots, Dockings, Maneuvers
- Pointing precision requirement < 30 arcsec
- 10% Events Impacted by disturbances
SAGE III Payload is comprised of 5 subsystems:

- Sensor Assembly [SA]
- Hexapod Mechanical Assembly [HMA]
- 2 Contamination Monitoring Packages [CMP]
- Disturbance Monitoring Package [DMP]
- Interface Adapter Module [IAM]

Attitude Fluctuations are measured by a Disturbance Monitoring Package [DMP]:

- Miniature Inertial Measurement Unit [MIMU]
- 3 Ring Laser Gyroscopes
  Sensitive to rotations as small as
  $1 \mu \text{radian} @ 200 \text{ Hz [ 0.001 arcsec / sec ]}$
- $1 \mu \text{radian}$ in elevation $\rightarrow 0.7 \text{m} - 2.5 \text{ m}$ in tangent height registration from a 400km orbital altitude
- Significant as only 30m of the 100m altitude error budget are allotted to spacecraft attitude
ACS and DMP Coordinate Systems:
- [ACS] Analysis Coordinate System fixed to ISS
  - ACS Z-axis → Nadir [normal TEA attitudes]
  - ACS X-axis → RAM [normal TEA attitudes]
- DMP is oriented to ACS such that axes form [normal TEA attitudes]:
  ~90 rotation about the \(Y_{ACS}, Y_{DMP}\) shared axis
  Other ACS orientations are possible but less common

Transform DMP Measurements → [Elevation, Azimuth Roll]:
- Remove Orbital Motion
- Filter Dither using Butterworth Filter
- Convert Gyro Positions to Rates
- Rotate through Quaternions:
  -Hexapod [HMA]
  -Static [alignment error due to
  -Wedge
  -DMP → SA Coordinate Transformation

DMP Elevation Correction [DMP Offset]:
- Map into Boresight Frame using
  Azimuth, Elevation Angles
- Mark Exceedances
- Down Sample to 64 Hz
**Pointing Registration Correction:**

- Assigns solar positions by scaling angular displacements from Nadir using a calculated Scan Rate as,

  \[ \text{Scan Rate} = \text{top edge-bottom edge/time difference} \]

- DMP correction for the same interpolated time is added

  *Fig 6 Left: Time series for Scan Rate Displacement, & DMP Offset*

  *Fig 6 Right: Limb Darkening Curves*

**Lower Atmospheric Scan Rate Correction:**

- Sun becomes occluded requiring Exo-Atmospheric scan rate extrapolation

  *Fig 7 Top: diverging red & blue boxes*

- DMP Offset added to Exo-Atmospheric, corrected scans then result in an improved lower atmosphere extrapolation

  *Fig 7 Bottom: aligned red & blue boxes*
Pointing Registration Correction

- Assigns solar positions by scaling angular displacements from Nadir using a calculated Scan Rate
- DMP correction for the same interpolated time is added

Animations

- Left Plot:
  - SDO HMIIC image
  - OverPlotted w angular positions w & wout DMP correction
- Right Plot:
  - Elevation Offset added to angular displacement

*Note: Depending on Disturbance angular rate and direction compared to those of the Mirror, the DMP Corrected Solar Position will lead or lag the Mirror Position*

Without DMP Correction (Black)
With DMP Correction (Blue)
Pointing Registration Correction

To illustrate the effect of the DMP Correction, an animation iterates through events showing Level 1 Intensity and Transmission Data:

- 50 Events: Largest # Disturbances
- BEFORE –and- AFTER Correction
- Left Plot: Solar Intensity vs Sun Position
- Right Plot: Transmission vs Altitude

Without DMP Correction (Black)
With DMP Correction (Blue)

*Note: Events w Sunspots*
Level 1 Transmission Improvements:

Fig 8 Unbinned Transmission for wavelengths (385, 601, & 1020 nm)

- [Top Row] Exo Atmospheric DMP corrects disturbances reliably
  - Order of Magnitude Decrease in noise
  - Similar Results observed for Entire Exo-Atmospheric Dataset

- [Bottom Row] Lower Atmosphere Disturbance present, smaller for this event, correction still performs reliably
  - Changes in overall pointing registration where large transmission gradients exist

Level 2 Retrieval Improvements:

Fig 9 [Left] Retrievals & Uncertainties for O3, 1 μ Aerosol, & H2O Vapor
Fig 9 [Right] Percent Differences for each Retrieval

- Reduction in Retrieval Uncertainties
- Reduction in Retrieval Noise itself
  - Note H2O Vapor reduction which is specifically sensitive to Transmission noise

- Beginning to Investigate the effects of the DMP Correction on the SAGE III/ISS Dataset as a whole
To Summarize:

- Sage operates on the ISS
- ISS experiences Attitude Fluctuations
- DMP Corrects for Pointing Mis-Registrations in 10% Events
- Level 1 & 2 Data Products result in lower uncertainties

Future Work:

- Analyzing Entire Dataset using DMP Correction
- Investigate Other Potential Improvements
  - Fine tune Filter Cutoff Frequency
  - Incorporate Azimuth & Roll Offsets
  - Incorporate DMP Flag for high level disturbances
  - Improve Understanding of:
    - Coordinate Transformation
    - ACS → DMP → SA
    - Mechanical Transfer Function